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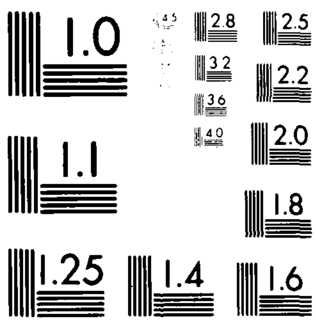

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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THE USE OF HOMOPOLAR GENERATOR AS ACCELERATION TRANSDUCER

E. G. Korolev, engineer.

There is presented an analysis of the work of electromechanical acceleration transducer with rotor in the form of a nonmagnetic disk from the positions of the theory of disk-type direct-current homopolar machines. The results of analysis can be used during calculation and designing of the transducer.

At the present time during the testing of general-industrial asynchronous electric motors, an original method of dynamic measurement of torsional moments was applied with the use of electromechanical acceleration transducer. By this method the recording instrument (for example, loop oscillograph) reproduces in a certain scale the characteristic of torsional moments $M=f(t)$ [1]

FOOTNOTE [1] V. I. Dolina, Device for measuring the angular

accelerations of electric motors in non-steady-state conditions. Author's certificate No. 171185. Bulletin of inventions 1965, No. 10.
END FOOTNOTE

The electromechanical acceleration transducer (Fig. 1) is a machine with a rotor in the form of nonmagnetic conducting disk 1 with thickness $\Delta_{\text{д}}$, rotating in air gap δ between two identical half-blocks of stator 2.

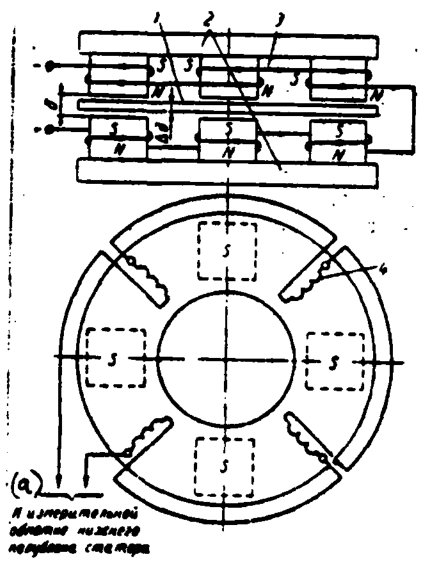

Fig. 1. Schematic diagram of eight-pole electromechanical acceleration transducer.

Key: (a) To measuring winding of bottom half-block of stator.

The transducer can be excited both by winding 3, uniformly distributed along the poles and supplied with direct current, and with the aid of permanent magnets. The measuring winding 4 of each half-block is also made distributed. Both windings are made in such a way that the pickups on the side of the external magnetic fields (for example, scattering field of the motor being tested) are counter directed and are mutually destroyed, and from measuring flows - are combined. Reduction of the interference level in the output signal, connected with the heterogeneity of the nonmagnetic rotor, is achieved by the application of multipolar magnetic system, which leads to growth of the impedance of the measuring circuit due to increase of the frequency of interference:

$$f_n = \frac{1}{2\pi} p\omega, \qquad (1)$$

where p - number of pairs of poles;

ω - angular velocity of rotor of acceleration transducer.

In the examined acceleration transducer the number of pairs of poles reaches p=12 and the area of its application is limited by the maximum speed of rotation 3000 r/min. At high speeds there is disturbed the linear dependence of the measuring magnetic flux on the speed of rotation because of the effect of flow of the reaction of the rotor on the excitation flow of the acceleration transducer.

In view of the absence of clear interpretation of the electromechanical acceleration transducer as an electric machine and the method of its electromagnetic calculation, it is difficult to answer the question about the possibility of its application during measurement of the torsional moments of electric motors with maximum speed of rotation greater than 3000 r/min.

As a matter of fact, to what type of generators should the electromechanical acceleration transducer pertain? It turns out that it can be considered as a homopolar generator with disk armature, operating in a mode close to a short circuit[1].

FOOTNOTE [1] E. G. Korolev. Report on the I All-Union conference on homopolar machines, 20 March 1969. ENDFOOTNOTE

In order to check this let us follow the process of application of emf e in the nonmagnetic conducting disk, which is rotated at angular velocity $\bar{\omega}$ in a constant magnetic field. In Fig. 2 by shading is shown the region of existence of excitation field, which is equivalent to the concept of electromechanical acceleration transducer with one pair of poles.

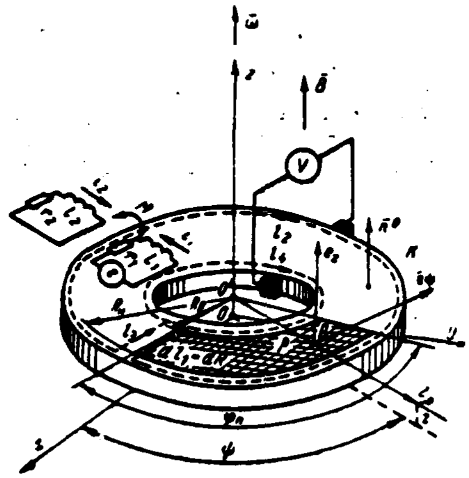

Fig. 2. Principle of action of two-polar electromechanical acceleration transducer with disk armature.

For ease of analysis we will assume that the excitation field in the indicated region is uniform, i.e., there is no edge effect.

On the electrons, rotating with the disk in the magnetic field, act Lorentz force:

$$F_{л} = q[\bar{v}\bar{B}], \qquad (2)$$

where q - charge of electron;

$\bar{v}$ - vector of linear velocity of movement of electron relative to the external magnetic field;

$\bar{B}$ - vector of induction of external magnetic field.

The region of the disk, in which there is no external magnetic field and the Lorentz force is equal to zero, is a kind of load for source of emf, having formed as a result of movement of electrons. Under the indicated conditions the expression of the law of electromagnetic induction has the following form:

$$e=\oint_{l} \bar{E}d\bar{l}=\oint_{l} \frac{\bar{F}_{л}}{q} d\bar{l}=\oint_{l} [\bar{v}\bar{B}_{1}]\, d\bar{l}, \qquad (3)$$

where $\bar{E}$ - vector of intensity of electric field, induced in the disk by external magnetic field.

For closed circuit K (Fig. 2), broken into sections, if we consider that on the second, third and fourth sections the results of integration are equal to zero, and vectors $\bar{v}$, $\bar{B}_1$ and $d\bar{l}_1$ are mutually perpendicular, we obtain:

$$e=\oint_{l} [\bar{v}\bar{B}_{1}]\, d\bar{l}=\int_{\bar{l}_1} [\bar{v}\bar{B}_{1}]\, d\bar{l}_1=\omega B_1 \int_{R_в}^{R_н} R dR=\pi B_1 (R_н^2-R_в^2)\, n=\Phi_1 n, \qquad (4)$$

where $R_н$ and $R_в$ - external and internal radii of pole respectively (Fig. 2).

R - current radius of disk;

Φ_1 - magnetic flux of excitation;

n - speed of rotation, r/s.

Thus is obtained the known expression of emf for disk homopolar direct-current generator [2]. In order to check this once more, let us assume the disk is rotated in a magnetic field, which exists not only in the region shaded in Fig. 2, but also where it was absent earlier, i.e., the disk is rotated between two ring-shaped poles. Then the voltmeter, connected to wipers, sliding one along the external, and the other along the internal edge of the disk, shows a value of only the emf calculated by us. This is the schematic diagram of homopolar generator with disk armature.

It is interesting whether the second Maxwell equation or Stokes theorem are applicable to the electromechanical acceleration transducer. For this purpose, using the relativistic method for the case of slowly moving media, let us try to prove that

$$\iint_S \mathrm{rot}_{\bar{n}^0} \dot{\bar{B}} d\bar{S} = \iint_S \mathrm{rot}_{\bar{n}^0} [\bar{v}\bar{B}]\, dS = \pi \dot{B}_0 (R_n^2 - R_s^2) n. \quad (5)$$

For the randomly selected point P of the disk, located at distance ρ from axis z within the pole it is possible to write in cylindrical

coordinates (Fig. 2)

$$\left.\begin{array}{l}\bar{\omega}=\omega\bar{e}_z;\ \bar{\rho}=\rho\bar{e}_\rho;\ \bar{v}=\omega\rho\bar{e}_\psi,\\ \bar{B}=B\bar{e}_z;\ \bar{E}=E_\rho\bar{e}_\rho=\omega\rho B\bar{e}_\rho,\end{array}\right\} \qquad (6)$$

where $\bar{e}_\rho, \bar{e}_\psi, \bar{e}_z$ - unit vectors.

Considering that the magnetic field of excitation is changed in azimuth (i.e., with respect to angle ψ) and exists only in certain boundaries along axis z we obtain

$$\operatorname{rot}\bar{E}=\frac{1}{\rho}\left\{\frac{dE_z}{\partial\psi}-\rho\frac{dE_\psi}{\partial z}\right\}\bar{e}_\rho+\left\{\frac{\partial E_\rho}{\partial z}-\frac{\partial E_z}{\partial\rho}\right\}\bar{e}_\psi+\frac{1}{\rho}\cdot \left\{\frac{\partial(\rho E_\psi)}{\partial\rho}-\frac{\partial E_\rho}{\partial\psi}\right\}\bar{e}_z=\frac{\partial E_\rho}{\partial z}\bar{e}_\psi-\frac{1}{\rho}\frac{\partial E_\rho}{\partial\psi}\bar{e}_z= =\omega\rho\frac{\partial B}{\partial z}\bar{e}_\psi-\omega\frac{\partial B}{\partial\psi}\bar{e}_z. \qquad (7)$$

Let us calculate now flow $\operatorname{rot}\bar{E}$ through surface S, limited by contour K, bearing in mind that with $\psi_1=0$, $B=B_0$, and with limiting scan angle ψ_2, close, but not equal to 2π, B=0 (Fig. 2):

$$\iint_S \operatorname{rot}_{\bar{n}_0}\bar{E}\,d\bar{S}=\iint_S\left(\omega\rho\frac{\partial B}{\partial z}\bar{e}_\psi-\omega\frac{\partial B}{\partial\psi}\bar{e}_z\right)\rho\,d\rho\,d_\psi\bar{e}_z= =-\omega\int_{R_B}^{R_H}\int_{\psi_1}^{\psi_2}\rho\frac{\partial B}{\partial\psi}d\rho\,d\psi=\pi B_0(R_H^2-R_B^2)\,n. \qquad (8)$$

The same result is obtained in the case of an ordinary disk homopolar generator, if we calculate flow $\bar{E}$ through surface S' bearing in mind that with $z_1=0$, B= B_0, and with $z_2=\infty$; B=0:

$$\iint_{S'}\operatorname{rot}_{\bar{n}_0}\bar{E}\,dS'=-\iint_{S'}\left(\omega\rho\frac{\partial B}{\partial z}\bar{e}_\psi-\omega\frac{\partial B}{\partial\psi}\bar{e}_z\right)d\rho\,dz\,\bar{e}_\psi= =-\omega\int_{R_B}^{R_H}\int_{z_1}^{z_2}\rho\frac{\partial B}{\partial z}d\rho\,dz=\pi B_0(R_H^2-R_B^2)\,n. \qquad (9)$$

The obtained results, incidentally, show that in homopolar

machines there do not exist electromagnetic paradoxes, about which is mentioned, for example in [2], the emf is not induced only in one idealized case, but namely if we assume that excitation field $B=B_0$ and with $z_2=\infty$. In electromechanical acceleration transducer and in this case there will be induced emf, since its magnetic field of excitation is interrupted in the azimuth.

Let us examine now the process of obtaining a signal, characterizing a change of the torque of the electric motor being tested. For this purpose let us offer that the nonmagnetic disk and the measuring coil are the primary and secondary windings respectively of the differentiating transformer (Fig. 2), for which are valid the following equations:

$$e = i_1 r_1 + L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}, \qquad (10)$$

$$0 = i_2 r_2 + L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}, \qquad (11)$$

where r_1, r_2 - ohmic resistances;

L_1, L_2 - leakage inductances;

M - mutual inductance of transformer.

If we accept that the signal of interest to us in the measuring circuit of the transducer $u_{вых}=i_2 r_2$ the equations (10) and (11) can be rewritten so:

$$e = i_1 r_1 + L_1 \frac{di_1}{dt} + \frac{M}{r_2}\frac{du_{\text{вых}}}{dt}, \qquad (12)$$

$$0 = u_{\text{вых}} + \frac{L_2}{r_2}\frac{du_{\text{вых}}}{dt} + M\frac{di_1}{dt}. \qquad (13)$$

For obtaining the expression, connecting the input signal of the differentiating transformer with the output signal, let us differentiate equation (12):

$$\frac{de}{dt} = r_1\frac{di_1}{dt} + L_1\frac{d^2 i_1}{dt^2} + \frac{M}{r_2}\frac{d^2 u_{\text{вых}}}{dt^2}. \qquad (14)$$

From (13)

$$\frac{di_1}{dt} = -\frac{u_{\text{вых}}}{M} - \frac{L_2}{r_2 M}\frac{du_{\text{вых}}}{dt}, \qquad (15)$$

$$\frac{d^2 i_1}{dt^2} = -\frac{1}{M}\frac{du_{\text{вых}}}{dt} - \frac{L_2}{r_2 M}\frac{d^2 u_{\text{вых}}}{dt^2}. \qquad (16)$$

After substitution of expressions (15) and (16) in (14), we obtain:

$$-\frac{M}{r_1}\frac{de}{dt} = u_{\text{вых}} + \frac{(L_1L_2 - M^2)}{r_1 r_2}\frac{d^2 u_{\text{вых}}}{dt^2} + \left(\frac{L_1}{r_1} + \frac{L_2}{r_2}\right)\frac{du_{\text{вых}}}{dt}. \qquad (17)$$

By taking the demagnetizing action of the reaction of the armature (disk) as completely compensated, after substituting instead of emf e, its value from (4), finally we write

$$-\frac{M\Phi_0}{r_1}\frac{dn}{dt} = u_{\text{вых}} + \frac{(L_1L_2 - M^2)}{r_1 r_2}\frac{d^2 u_{\text{вых}}}{dt^2} + \left(\frac{L_1}{r_1} + \frac{L_2}{r_2}\right)\frac{du_{\text{вых}}}{dt}. \qquad (18)$$

By analyzing the obtained result, we come to the conclusion that even in the case of complete compensation the effect of the reaction on the main flow of excitation Φ_0 the output signal $u_{\text{вых}}$, obtained as a result of differentiation of e reproduces the characteristics of torques of the tested motor through acceleration $\frac{dn}{dt}$ with error

characteristic for differentiating transformer, which, basically, depends on the time constants of nonmagnetic disk $\tau_1 = \frac{L_1}{r_1}$ and measuring circuit $\tau_2 = \frac{L_2}{r_2}$.

Due to decrease of the time constants τ_1 and τ_2 (for example, by means of increase of the ohmic resistances r_1 and r_2) the accuracy of differentiation can be raised, but in this case the level of the output signal is lowered, i.e., the scale of the curve of engine torques M=f(t). Nevertheless in order to reduce to acceptable the scale of recording, it is necessary, as follows from (18), to increase the excitation flow of the transducer

The stated reasonings are also valid for multipolar electromechanical acceleration transducer. It should be considered as p homopolar disk-type generators, each of which operates in a mode close to short circuit. In the measuring circuit of the multipolar transducer, consisting of p signal coils, there is produced summation of the signals from each generator (Fig. 3).

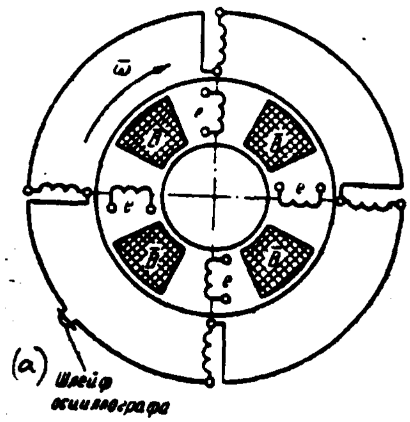

Fig. 3. Principle of action of eight-pole electromechanical acceleration transducer.

Key: (a) Oscillograph loop.

Let us find now the electromagnetic generator moment of the electromechanical acceleration transducer and clarify the error introduced by it into the measurement of the torques of the tested motor. For determination of this moment let us use known [1] expression of tangential force, acting on the elementary conductors of the rotor disk:

$$dT_{э} = [\bar{j}B]\,dV,$$

where $\bar{j}$ - vector of current density in the rotor disk;

dV - element of volume of rotor disk.

As applied to our case we have (Fig. 2): current density within one pair of poles

$$j = \frac{I_{\text{д}}}{R\varphi_{\text{п}}\Delta_{\text{д}}}, \qquad (20)$$

where $I_{\text{д}}$ - current in the disk within the pair of poles;

R - current radius of disk;

$\varphi_{\text{п}}$ - pole angle;

$\Delta_{\text{д}}$ - thickness of disk.

induction in the air gap:

$$B_{\delta} = \frac{\Phi_{\delta}}{\pi(R_{\text{н}}^2 - R_{\text{в}}^2)}; \qquad (21)$$

element of volume of disk within the pair of poles:

$$dV = R\varphi_{\text{п}}\Delta_{\text{д}}dR. \qquad (22)$$

Taking into account (20), (21) and (22) we obtain the elementary electromagnetic moment of the rotor disk:

$$dM_{\text{э}} = RdT_{\text{э}} = \frac{I_{\text{д}}\Phi_{\delta}}{\pi(R_{\text{н}}^2 - R_{\text{в}}^2)} RdR. \qquad (23)$$

By performing integration of (23) within the pole, we find the electromagnetic generator moment of a two-pole acceleration transducer:

$$M_э = \int_{R_в}^{R_н} \frac{I_д \Phi_\delta}{\pi (R_н^2 - R_в^2)} R dR = \frac{I_д \Phi_\delta}{2\pi}. \qquad (24)$$

For electromechanical acceleration transducer with p pairs of poles the expression (24) takes the form:

$$M_э = \frac{p I_д \Phi_\delta}{2\pi}, N\cdot м, \qquad (25)$$

where current of disk $I_д$ in amperes, magnetic flux Φ_0 in webers.

If as before we consider that the reaction of the armature (disk) in the transducer is compensated, then from (25) it follows that the electromagnetic generator moment of the transducer with $\Phi_\delta = const$ linearly depends on the speed of rotation of the disk. The equation of motion taking into account this moment can be written as:

$$M - M_э = M_j, \qquad (26)$$

where M - electromagnetic moment of the tested motor;

M_j - dynamic moment, corresponding to the energy of the rotating mass.

In Fig. 4 is presented the qualitative picture of the result of recording of the curve of torques of asynchronous motor taking into account the effect of electromagnetic moment of the acceleration transducer, from which we see that the error of measurement depends on the speed of rotation of the disk n and on the magnitude of

excitation flow $\Phi_{в}$. The given error increases with increase of both speed and excitation flow.

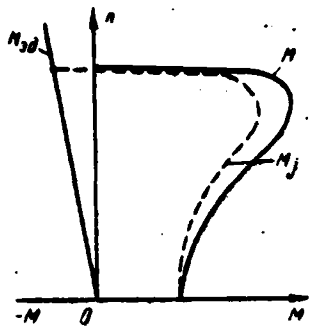

Fig. 4. Curve of torques of asynchronous motor taking into account the electromagnetic generator moment of electromechanical acceleration transducer.

By analogy with disk homopolar generator with ring-shaped current-collector it is possible to consider that the reaction of the armature in the transducer carries a transverse character. The magnetizing force F_{ea} additionally magnetizes the steel sections of magnetic circuit, which leads to increase of its magnetic resistance R_{μ} and, consequently, - to decrease of the main excitation flux $\Phi_{в}$.

Considering the work of the armature (disk) in the mode, close to short circuiting, and increase of magnetizing force F_{ea} with

increase of the speed of rotation, we come to the conclusion that without the application of special measures for compensation of the demagnetizing action of the transverse flow of the reaction of the armature, the results of measurements of the torques of the tested motors are far from true.

CONCLUSIONS

1. The electromechanical acceleration transducer is a homopolar generator, operating in a mode close to short circuiting.

2. Electromagnetic calculation of the electromechanical acceleration transducer can be done with the use of the known method of calculation of homopolar machines of direct current.

3. In the electromechanical acceleration transducer it is not possible to compensate the magnetizing action of the reaction of the armature with the aid of a compensating winding, connected in sequence with the circuit of the armature, as is done in ordinary homopolar generators.

4. For exclusion of the nonlinear dependence of measuring

magnetic flux of the transducer on the speed of rotation it is necessary to either use a highly saturated magnetic system of excitation, or generally to get away from the application of ferromagnetic magnetic circuit. The latter can provide considerable increase of the upper limit of the speed of rotation of the transducer, which in this case is limited only by the mechanical strength of its rotor. But deprivation of the excitation system of ferromagnetic magnetic circuit requires considerable increase of power, supplied to the excitation circuit of the acceleration transducer.

In conclusion let us note that there can be similarly analyzed the processes, occurring in electromechanical acceleration transducer with hollow nonmagnetic rotor, and also in other electrotechnical apparatus, similar in construction to electromechanical acceleration transducer and excited by direct current or permanent magnets (for example, electromagnetic brake, electromagnetic sliding coupling etc.).

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2. P. Moon, D. E. Spencer. Journal of the Franklin Institute, 1955, No. 5, v. 260.

DIRECT-CURRENT HOMOPOLAR MACHINE WITH SODIUM-POTASSIUM RING-SHAPED CONTACTS

L. A. Sukhanov, Cand. tech. sciences, G. A. Karmanov, eng.

The specific features of the construction of direct-current cylindrical-type homopolar machine with sodium-potassium ring-shaped contacts are described. There is presented the arrangement of the circulation system of the alloy and its operation in different modes. The results are presented of the experimental investigation of homopolar machine.

A region of application of homopolar machines is the installations with low voltages and high currents. The use of liquid metals and their alloys for slip ring makes it possible to create very economical and reliable machines, resistant to large overloads in terms of current in shock conditions [1]. Of the greatest interest is the application of eutactic sodium alloy with potassium, which is not toxic, with respect to its mechanical properties approaches water

and has electric conductivity only 3.34 times less than that of steel.

Physical properties of eutectic alloy

Composition ... 23 o/o Na, 77 o/o K

Density at 100°C, kg/m^3 ... 887

Melting point, °C ... -10

Boiling point, °C ... 784

Electric resistance (at 100°C), Ω•m ... $41.61 \cdot 10^{-3}$

Specific heat, kcal/kg•deg ... 0.269

Viscosity, $N \cdot s/m^2$ ... $54.6 \cdot 10^{-5}$

Thermal conductivity, W/m•deg ... 24.9

The practical use of alloy NaK is connected with the necessity

of solution of a number of technical questions. The alloy is rapidly oxidized in air and loses its positive qualities, violently reacts with water, eats away the contact surface of some metals during prolonged work. In connection with this the working zone of the slip ring (or machine on the whole) should be sealed and filled with inert gas with small excess pressure above atmospheric, a system of feeding the alloy into the contact zone and its removal is provided, purification and cooling of the alloy are provided, etc.

For the purpose of accumulation of experience on the creation and operation of homopolar machines with the use of alloy NaK for slip ring in 1967 there was created the appropriate laboratory installation, on which some investigations were conducted.

In Fig. 1 is shown the overall view of homopolar machine. Its nominal data: power 3.8 kW, voltage 0.75 V, speed of rotation 5000 r/min, design efficiency 90 o/o. Overall weight 40 kg. Excitation is independent.

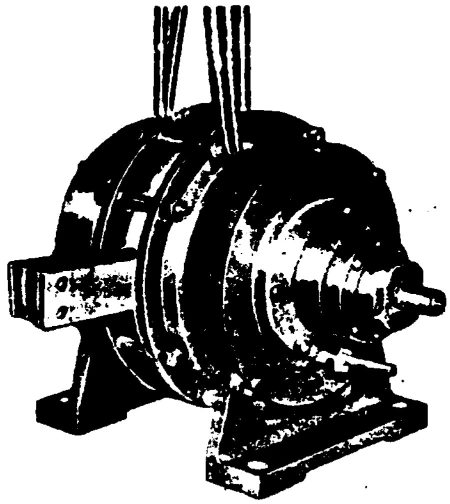

Fig. 1. Overall view of homopolar machine.

Specific features of construction of the machine. Longitudinal section of the machine is shown in Fig. 2, its main elements and geometric dimensions are indicated there.

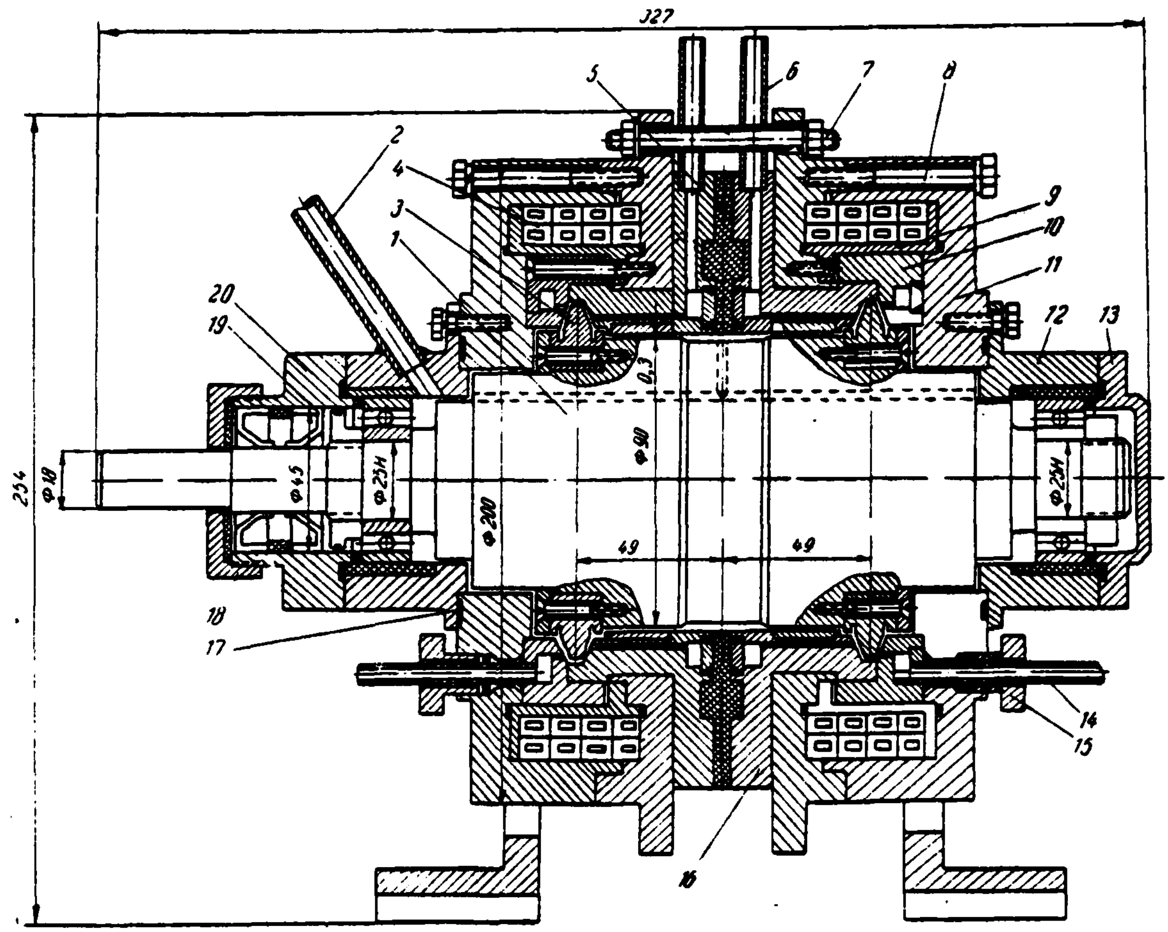

Fig. 2. Longitudinal section of the machine.

1 - rotor; 2 - input of inert gas; 3 - contact ring; 4 - excitation winding; 5 - seal course; 6 - input of alloy; 7 - ring of middle pole of stator; 8 - copper compensating core; 9 - sleeve; 10 - external

ring of current-collecting device; 11 - ring of extreme pole of stator; 12 - bearing shell; 13 - annular cover; 14 - outlet of alloy; 15 - packing nut of outlet; 16 - output buses; 17 - vacuum rubber seal; 18 - locking nut; 19 - armored collar; 20 - oil seal housing.

The machine is with cylindrical massive rotor and two current-collecting ring-type contact devices [2]. The internal cavity of the machine is sealed. The rotor has one outlet end of the shaft. On the rotor on two sides the removable contact rings are mounted and attached by screws. This makes it possible to manufacture them from various materials, simplifies the technology of application of coatings, provides assembly of the machine with stator nondetachable along the horizontal axis.

The stator is made from four steel rings. The two middle rings are drawn in by insulated axial pins. Between them are located copper buses, separated by a fiber glass laminate washer, seated on epoxy resin. To the middle rings are screwed the extreme poles, covering the coils of the excitation winding. Such a construction is quite technological and makes it possible to provide good sealing due to the application of recesses along the circumference and seals made of vacuum rubber.

The output buses are connected with the aid of copper cores with

external rings of current-carrying devices. As a result the load current flows through the core in the direction, opposite the current of the rotor, by which compensation of the magnetic field is achieved.

The annular construction of the machine made it possible to relatively simply make the external slip rings with a complicated system of annular and radial channels. The feed of the alloy into the contact zone is accomplished through the output buses, compensating cores, external ring-shaped electrode of the current-carrying device with output signal of assembled annular collector. Circulation of the alloy is provided by the hydraulic head, appearing during rotation of the rotor. The input and output channels with diameter 1.5 mm are uniformly arranged along the circumferences of the external slip ring. The amount of the head is determined by the difference of the diameters of circumferences, on which the indicated channels are located. For the given machine it is 6.4 mm.

The excitation winding, creating radial magnetic field in the gap of the machine, is made from hollow copper (section 8x5.1 mm). The coil is mounted on the sleeve made of nonmagnetic material (duraluminum), which is clamped between the poles of the stator. This eliminates the alloy falling on the winding and does not require sealing of its leads. The internal channel of the winding is used for

cooling. In order to weaken the magnetic leakage flux, the bearing shells are made of brass. For preventing closing of currents through them there are pressed in fiber glass laminate bushings. In order to reduce to minimum the leakage of argon from the cavity of the machine, on the side of the free end of the shaft are installed two armored collars, housing or oil seal and washer with seal, covering the gap during pumping out of air. Inert gas is supplied into the cavity of the machine through a special inlet. In the rotor are channels for the connection of three cavities in the machine, which are formed with the presence of alloy in the ring-shaped contacts during operation.

Circulation system. Its purpose - to provide circulation of the alloy through the contact zones of current-collecting devices, the possibility of preparation of the alloy for work and its drain, the creation of a technical vacuum in the system and filling with inert gas, monitoring the work.

In Fig. 3 is given the schematic diagram of the circulation system with indication of the main elements.

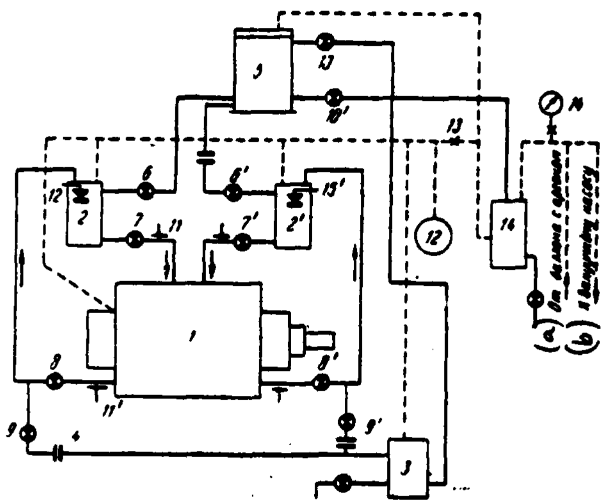

Fig. 3. Schematic diagram of laboratory circulation system. --- - pipes for alloy; - - - - hoses for inert gas. 1 - homopolar machine; 2 - pressure tank; 3 - overflow tank; 4 - insulating flange; 5 - preparatory tank; 6-10 - bellows-type valves; 11 - thermocouples; 12 - receiver; 13 - movable clamp; 14 - pressure gauge; 15 - alloy level indicator.

Key: (a) From cylinder to argon. (b) To vacuum pump.

The largest cut pieces of sodium and potassium in the necessary proportion in terms of weight are placed in tank 5. The tank is

hermetically sealed and in the entire system with fixed rotor of the motor there is produced pumping cut of air with a pump to technical vacuum. The air gap between the rotor shaft during pumping out is covered by lock washer with sealing washer.

With closed bellows-type valves 6, 6', 10, 10' there is produced heating of metal to 150-200°C, and after 30-minute holding the formed alloy is cooled. During cooling the oxides rise upwards to the surface. This makes it possible to fill the tanks 2, 2' with pure alloy NaK. The quantity of alloy is prepared 2-3 times more than is required for operation. Further into tanks 5 and 14 from the cylinder is supplied technical argon at pressure 1.2 at. Clamp 13 prevents the technical argon from falling into the working part of the system. A portion of the alloy by opening valve 10 overflows into the argon purifier 14. This gives the possibility to fill the system (having removed clamp 13) with pure argon, having passed through a layer of alloy NaK in oxidizing agent 14. Alternately by opening valves 6 and 6' there is produced filling of tanks 2 and 2' by the electric level indicators 15 and 15' respectively.

In the case of operation of homopolar machine in the generator mode it is expedient to feed the alloy from tanks 2 and 2' into the zone of slip ring with rotating rotor, opening valves 7, 7', 8, 8' with closed valves 9, 9'. In the motor mode starting is accomplished

without load on the shaft, in order to give the rotor the possibility of rapidly accelerating and thereby limiting the possible fall of alloy into the cavity of the machine. In the process of operation of the machine in the system due to receiver 13 there is kept a small pressure excess (approximately 0.1-0.2 atm(gage)).

Before stopping the generator there is removed excitation and valves 7, 7' are closed, and then 8, 8'. Further the free drain of alloy from the system is produced into tank 3 with opening of valves 9, 9'. Transfer of alloy from tank 3 into tank 5 is possible. For this, into tank 3 under pressure on the order of 1.5 at is fed argon (preliminarily the tank is separated from the main system by the clamp). The temperature of the alloy is controlled by thermocouples at the input and output 11, 11' of the alloy from the machine.

In the circulation circuits of alloy NaK there were used copper hollow tubes, and in the circuits of inert gas - hoses made of vacuum rubber. Since the left and right circuits of circulation of the alloy are located under potentials of different sign during operation of the machine, then electrical insulation from each other (4) is provided. The experience of operation on the described laboratory circulation system showed its good efficiency and operational reliability.

For homopolar machines of industrial application the circulation system can be simplified. So, for pouring into the system it is possible to use a ready pure alloy (from the container), supply earlier purified inert gas, perform overflow into portable tank, etc. It is necessary to reduce to minimum the length of connecting pipes and the volumes of tanks. This substantially reduces the volume of NaK alloy necessary for work.

Test results. The operation of homopolar machine in generator and motor modes with various loads occurred without vibrations and noise not only with nominal speed of rotation (5000 r/min), but also with its increase to 7500 r/min. The circulation system satisfacturally provided the prescribed conditions. No leakages of alloy and disturbances of sealing of the system were observed.

Heat tests were conducted without the supply of water into channels of the excitation winding. In Fig. 4 is shown the change of temperatures of alloy and separate elements of the machine with load current 2400 A.

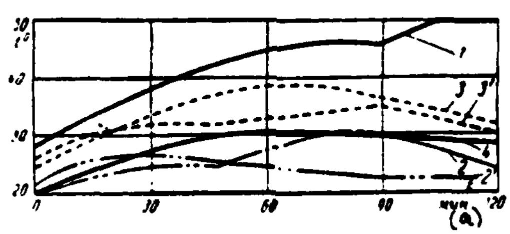

Fig. 4. Thermal conditions of homopolar machine with load current 2400 A. 1 - bearing on the side of drive; 2, 2' - alloy at inlet of circuits into machine; 3, 3' - alloy at outlet of circuits from machine; 4 - excitation winding.

Key: (a) min.

In Fig. 5 are shown some results of electrical tests.

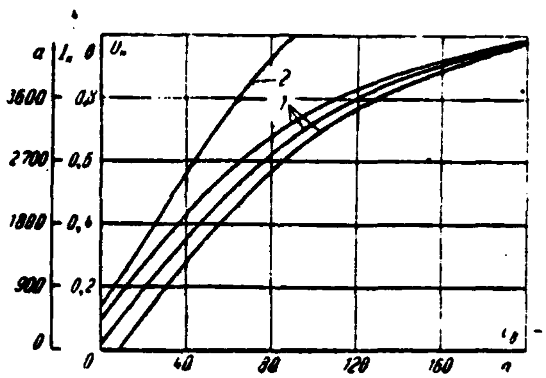

Fig. 5. Characteristics of no-load operation (1) and short circuiting (2) with n=5000 r/min.

Since the magnetic circuit is made from massive steel elements, then in the curve of no-load operation is observed a relatively wide hysteresis loop. On the graph is given the same average curve of magnetization. Excitation current 118 A, close to design value, with respect to characteristics of no-load operation corresponds to

nominal voltage 0.75 V.

When taking the characteristic of short circuiting the armature circuit was closed to the shunt. The resistance of the short-circuited circuit, measured with current 3000 A, was $7 \cdot 10^{-5}$ Ω, i.e., the contact between current-carrying elements is good.

The homopolar machine was tested both in generator and in motor modes. For power supply in motor mode there was used a direct-current high-power machine, operating in steady-state short-circuit mode.

It is interesting to note that starting the motor (performed without load on the shaft) occurred successfully without feeding of alloy into contacts. The alloy remaining in the annular channels from the previous work of the motor was sufficient for providing contact between the internal and external rings of the current-collecting device.

In Fig. 6 is shown the curve of efficiency of homopolar electric motor, determined for different speeds of rotation. Here is given the required power of the motor, with which the efficiency is found.

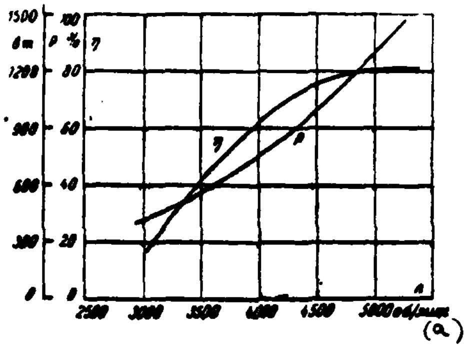

Fig. 6. Curve of efficiency of homopolar electric motor.

Key: (a) r/min.

The homopolar machine was tested for two months without replacement of alloy in the circulation system. During this period of time the seal of the internal cavity of the machine was not disturbed. In overall complexity the machine worked with interruptions of 100 h. In this case the mode of continuous operation was 24 h.

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